

The University of Chicago

THE GENESIS OF THE TRI-STATE
ZINC AND LEAD ORES

A PART OF A DISSERTATION SUBMITTED TO
THE FACULTY OF THE DIVISION OF THE
PHYSICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY

1935

By
JOHN RIDGE

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THE GENESIS OF THE TRI-STATE ZINC AND LEAD ORES.

JOHN RIDGE.

INTRODUCTION.

THIS paper deals with the petrography of the jasperoid, the mineral paragenesis, and certain considerations bearing on the origin of the ores. Some 108 specimens, representing many different parts of the area, were examined; these were collected by Professor E. S. Bastin, Mr. John Svatik, and the writer. Through the courtesy of Mr. J. H. Meyers, City Commissioner of Joplin, Missouri, the writer was also able to study the specimens in the Tri-State Mineral Museum.

The specimens were examined under binocular and reflecting microscopes and the evidence so obtained was used in testing the hypotheses offered as to ore deposition. The supervision of Professor Bastin has been invaluable throughout the study. Professor C. H. Behre, Jr., has kindly read and criticised the paper.

THE JASPEROID.

Composition and Color.—The jasperoid is composed of xenomorphic crystals of quartz, only distinguishable under the microscope, and dark brown dots and clusters of organic material between the quartz crystals or rarely included in them. The diameters of the quartz crystals vary from those invisible up to one millimeter. Apparently this organic material was derived from bituminous matter associated with the Boone formation prior to mineralization. To test the organic nature of the material, a thin section of the jasperoid was boiled in dilute hydrochloric acid to remove the intergrown sulphides. This treatment caused no diminution in the amount of dark coloring matter. An analysis of the jasperoid by Mr. George H. Otto showed con-

siderable organic matter in the material, confirming the analysis of Steiger.¹ Since there is nothing else recognizable that could give the color after the sulphides had been removed, the dark brown coloring must be due to organic matter.

Development of the Jasperoid-Cemented Breccias.—Hand specimens showed the following stages of change in the production of the jasperoid-cemented breccias from the Boone limestone:² (1) the Boone formation was subjected to tectonic fracturing of the chert, with emplacement of the limestone between the chert fragments; (2) replacement of limestone to a varying extent by dolomite;³ (3) replacement of this dolomitic limestone largely by jasperoid; (4) partial replacement of the jasperoid by a second generation of dolomite, perfect crystals being formed in the vugs; these cap and intergrow with the tiny dark quartz crystals which grade into the jasperoid, and were formed when silica was deposited in the vugs in the breccias; (5) introduction of the sulphides which intergrew with and capped this younger dolomite.

Evidences for the Replacement Origin of the Jasperoid.—The following points suggest replacement origin for the jasperoid: (1) matrices of the breccias grade from limestone, to part limestone and part dolomite, to part dolomitic limestone and part jasperoid, and finally to jasperoid; (2) in thin sections of jasperoid, dolomite crystals are found which show ragged replacement outlines against jasperoid and contain small quartz crystals in their otherwise unattacked centers; (3) many chert fragments have outlines that match those of adjacent fragments; they therefore could not at any time have been deprived of the support of a matrix to hold them in the same relative position;

¹ Van Hise, C. R., and Bain, H. F.: Lead and Zinc Deposits of the Ozark Region. U. S. Geol. Surv., 22nd. Ann. Rept., Pt. II, p. 121, 1902.

² Weidmann, Samuel: The Miami-Picher Zinc-Lead District, Oklahoma. Okla. Geol. Surv., Bull. 56, pp. 14 and 61, 1932.

Smith, W. S. T., and Siebenthal, C. E.: The Joplin District. U. S. Geol. Surv., Folio No. 148, pp. 3 and 13, 1907.

³ Dolomite was tested for in this investigation by the use of Lemberg's solution. (See Fairbanks, E. E.: A Modification of Lemberg's Staining Method. Amer. Miner., vol. 10, pp. 126-127, 1925.)

(4) in some of the jasperoid there are grains of glauconite similar to those found in many parts of the Boone formation, and thus probably residual in the jasperoid after the replacement of limestone.⁴

Origin of Vugs in the Jasperoid.—It has been suggested that the chert in the Boone formation was fractured by slumping due to the solution of limestone associated with it. In the open spaces thus formed the jasperoid was supposed to have deposited as a silica gel which was later dehydrated and crystallized to form the jasperoid, leaving the unfilled portions as vugs. However, this does not agree with the evidence that the jasperoid was formed by the replacement of the dolomitic-limestone matrix. Since it is certain that some of the jasperoid, at least, was formed by replacement, and since all the jasperoid, even in thin section, appears to be much the same, it is reasonable to suppose that, if open-space filling were important in the production of jasperoid, the type of crystallization in such filled spaces should be similar to that produced by replacement of solid rock. However, the examination of hand specimens shows that the silica deposited in vugs crystallized as automorphic quartz; whereas that deposited by replacement of dolomitic limestone assumes the xenomorphic granular texture already mentioned. This appears to furnish a criterion of distinction between silica which replaces dolomitic limestone and that which fills open spaces. From an inspection of the hand specimens, it appears that the filling of open spaces played only a small part in silicification.

From the above, it appears most likely that the vugs in the jasperoid were inherited from the dolomitic limestone. There are two ways in which vugs could have developed before jasperoid mineralization: (1) by an incomplete filling of the spaces between chert fragments at the time the breccia was formed, and (2) by later solution of limestone and dolomitic limestone. These vugs are commonly more round than elongate. In a general way, the larger the percentage of chert in the walls of the vug, the more likely it is that it was formed by incomplete filling.

⁴ Tarr, W. A.: Personal communication, March, 1934.

However, there are some narrow, elongate vugs in the dolomitic limestone, apparently formed mainly by solution, and filled with dolomite which is much more coarsely textured than that of the main mass of the dolomitic limestone. Such dolomite is clearly of a later generation than that which has formed part of the matrix, since these elongate vugs, in many cases, run into the larger, more rounded ones where the coarser dolomite crystallized in typical saddle-shaped forms sharply bounded by the dolomite of the walls.

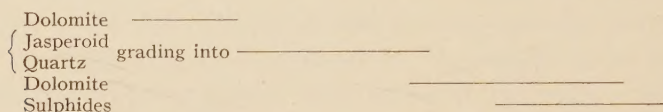
There is another possible way in which vugs might have developed in the jasperoid. If the material had replaced the limestone as a silica gel, it would have undergone later dehydration and crystallization. These processes would have produced shrinkage cracks in the jasperoid unless they took place under pressure. If the gel had been emplaced under sufficient pressure to prevent the formation of shrinkage cracks, the gel would have been forced into the vugs inherited from the dolomitic limestone matrix and would have filled them. Since such vugs still exist, the jasperoid could not have been derived from the dehydration and crystallization of a silica gel under sufficient pressure to prevent the formation of shrinkage cracks.

Therefore it appears that, if the jasperoid were emplaced as a silica gel, it would show cracks which could be definitely related to shrinkage. It seems probable, from their form, that the larger, more rounded vugs were not due to shrinkage, but there remains the possibility that some of the elongate ones were. Even this possibility, however, seems excluded, since in both the rounded vugs (almost certainly inherited from the dolomitic limestone matrix) and the elongate vugs, the sequence and general character of the mineralization is the same; a criterion which, in the absence of better ones for differentiating between cracks formed by shrinkage and elongate vugs formed by solution and inherited from the preceding matrix, seems applicable here. These facts would argue against the jasperoid having been deposited as a silica gel.

PARAGENESIS.

Before the results of the paragenetic studies are presented, it must be emphasized that they are derived from the inspection of a large number of specimens, since complete mineral development in any one specimen is exceptional.

First Stage of Mineralization.—The paragenetic relations of the first minerals of this stage have already been described and may be diagrammed as follows:



The sulphides cap but do not intergrow with the dark quartz. From this it is evident that the sulphides are completely separated from the dark quartz, and probably from the jasperoid, in time of deposition. The presence of the sulphides in ragged, disseminated masses, irregular veinlets, and automorphic crystals in the jasperoid points to their replacement of it.

Pyrite was the first sulphide to form; it replaces both dolomite and jasperoid, and is, in turn, replaced by both sphalerite and galena. Facts that carry evidence for these relations are: (1) pyrite is found in dolomite and jasperoid as automorphic crystals and in veinlets and disseminated masses occupying cracks and cleavage planes; (2) pyrite is cut by ragged veinlets of galena, bearing pyrite inclusions, but there are no galena inclusions in pyrite; (3) there are ragged masses of pyrite in sphalerite but none of sphalerite in pyrite.

There is no evidence of overlap in the time of deposition of pyrite with that of sphalerite and galena. There is, for example, no intercrystallization with crystal boundaries of each mineral showing in the same neighborhood.

Galena and sphalerite show the following inter-relations: (1) dolomite is capped by and intergrown with galena which is partially capped by and intergrown with sphalerite; (2) dolomite is capped by and intergrown with sphalerite which is, in turn, par-

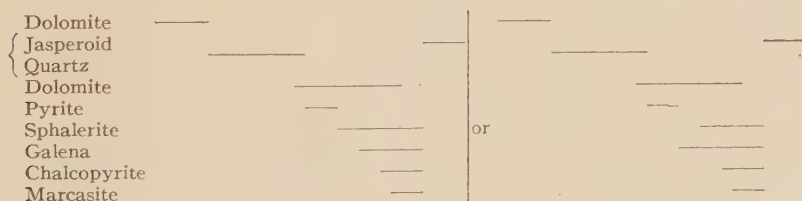
tially capped by and intergrown with galena. Sphalerite began to deposit first more often than galena. In a few cases where galena is absent, sphalerite began to deposit before dolomite, but this is exceptional.

Chalcopyrite is intergrown with and extends beyond sphalerite and galena, and is intergrown with and caps dolomite. In one case, the deposition of chalcopyrite began before that of galena, but here the chalcopyrite was many times as abundant.

Marcasite is intergrown with and extends beyond galena, sphalerite and chalcopyrite; and is intergrown with and caps dolomite. The intergrowth is considerable with chalcopyrite, intermediate with sphalerite, and very slight with galena, indicating overlap in the time of deposition. However, there are no specimens that show any of the four sulphides completely capping one another but, rather, the ones that began to deposit later merely extend beyond the others. In such situations, all the sulphides must have been deposited together for at least part of the time. Whether deposition stopped at the same or different times cannot be determined from an inspection of the hand specimens alone. In the latter part of this paper the writer will present a hypothesis to explain the relations of the four sulphides to each other. This hypothesis specifies that the sulphides stopped precipitating at the same time. The paragenesis diagrams are constructed on this basis.

The sulphides are capped by a colorless quartz lighter than that which grades into the jasperoid. Thus, there is demonstrated a hiatus in silica deposition.

The paragenesis established for the first stage of mineralization is given below:



Second Stage of Mineralization.—After the end of the precipitation of the four sulphides and the second generation of silica, there was a definite hiatus in mineral deposition, during which time a fracturing of the minerals of the first generation and of the enclosing rocks occurred. In the fissures and vugs developed were deposited the minerals of the second stage.

The great bulk of the second stage is composed of clear calcite, which fills the fissures and lines the vugs with scalenohedral and rhombic crystals. These cap, but do not overlap with or replace, any of the minerals of the first stage. Paragenesis of this part of the series is shown below:

First stage sulphides	-----	
First generation light quartz		-----
Fracturing		xxxxx
Calcite, etc.		-----

A second generation of pyrite is also present and forms small cubes capping first-generation sphalerite but not intergrown with it. Where marcasite is also present, its relations differ from those of the second generation of pyrite in that the marcasite not only caps the sphalerite but also is intergrown with it. This suggests that second-generation pyrite is later than first-generation marcasite, although the two are nowhere in contact. According to Tarr, large crystals of calcite are found in the area; these contain concentric rings of pyrite, indicating contemporaneity.⁵

The last event in the second stage of mineralization was the development of simple crystals of enargite.⁶ These cap, but are not intergrown with, first-generation sphalerite and marcasite; but cap and are slightly intergrown with calcite. Since the second generation of pyrite is so much more intimately intergrown with calcite than is the enargite, it is probable that enargite deposition began after that of pyrite had ceased. The paragenesis of the second-generation minerals is shown below:

Calcite	-----
Pyrite	-----
Enargite	-----

⁵ Tarr, W. A.: Personal communication, March, 1934.

⁶ First recognized by E. T. McKnight. (Jour. Wash. Acad. Sci., vol. 21, no. 15, p. 369, 1931. ECON. GEOL., vol. 30, pp. 62-64, 1935.)

Summary.—The following table presents in diagrammatic form a summary of the paragenetic relations described. It should be emphasized that all the evidence for the paragenetic series cannot be given in full in the space available.

TABLE I.

Limestone	_____	
Chert	-?- _____	
Brecciation		xxxxxx
Dolomite	_____	
Jasperoid		
{ Quartz grading into	_____	
Dolomite		
Pyrite		_____
Sphalerite		_____
Galena		_____
Chalcopyrite		_____
Marcasite		_____
Fracturing		xxxxxx
Calcite		_____
Pyrite		_____
Enargite		_____

EVALUATION OF OBSERVATIONAL EVIDENCE.

All the more acceptable hypotheses brought forward to explain the origin of the Tri-State ores agree on the *epigenetic* origin of the deposits, but there is disagreement as to the source and the physical and chemical character of the mineralizing solutions. It will be recalled that the three leading hypotheses stipulate that the ores were deposited by the agency of (1) descending ground water,⁷ (2) ascending artesian solutions,⁸ and (3) ascending

⁸ Siebenthal, C. E.: Zinc and Lead Deposits of the Joplin Region. U. S. Geol. Surv., Bull. 606, p. 13, 1915.

thermal solutions of magmatic origin.⁹ In the discussion of the observational evidence no mention will be made of the hypothesis involving downward-moving ground water. This omission is intentional, since all the phenomena under consideration are accounted for in practically the same manner by this hypothesis and the artesian one.

Two Stages of Mineralization.—The separation of the mineralization into two distinct stages is the most noticeable fact brought out by the paragenetic studies. Since the minerals developed in the two stages are different, it is logical to suppose that the solutions from which they were deposited were different. This change in the nature of the solutions appears to be related to fracturing.

There is nothing in the mechanism provided by the artesian hypothesis to suggest that fracturing should bring with it a change in the character of the ore-bearing solution. However, supposing that the fracturing during the hiatus in mineral deposition were a fortuitous coincidence, the development of minerals different from those of the first stage is still incompatible with the artesian mechanism. For example, one of the changes was the development of pyrite instead of marcasite. Under the artesian hypothesis, the solutions would in each case have been acid. Although pyrite and marcasite can be deposited side by side at relatively low temperature, a change from the deposition of marcasite alone to that of pyrite alone could, under acid conditions, only be effected by a rise in temperature. This is, of course, not only incompatible with the artesian hypothesis but in diametrical contradiction to it.

On the other hand, the presence of two stages of mineralization becomes a strong argument for the hydrothermal hypothesis. Successive phases of mineralization are a common feature of epithermal deposits,¹⁰ where fracturing or brecciation of the minerals may be followed by the deposition of an entirely new suite of minerals. This may be due to the movement attendant on

⁹ Weidmann, Samuel: *Op. cit.*, pp. 77-84.

¹⁰ Lindgren, Waldemar: *Mineral Deposits*, 3rd. ed., pp. 521-524, 1928.

fracturing, closing old sources of supply and opening the way for either new solutions from other parts of the old source, or for new solutions from a new source.

Thus, the evidence furnished by the two stages of mineralization is seen to favor the hydrothermal hypothesis over the artesian one.

Two Stages of Quartz Deposition.—Within the first stage of mineralization there is a hiatus in quartz deposition. Such a hiatus is more characteristic of hydrothermal than ground-water deposits.

Presence of Enargite.—Enargite was deposited during the second stage of mineralization, showing that the ore-bearing solutions of that stage were igneous in origin. Minerals of the first stage might still have been deposited by the artesian mechanism, but since an igneous source furnished the second-stage solutions, the first-stage solutions might also well have had an igneous source.

Thus the evidence furnished by the presence of enargite favors the hydrothermal over the artesian source for minerals of both stages.

Presence of chalcopyrite.—It is a well known principle that a double salt, such as chalcopyrite, when dissolved in ground water, usually reprecipitates not as a double salt but as single ones. Wells states in this connection that: "The solubilities of the several sulphides, however, differ so greatly that complete separations by fractional precipitation are possible."¹¹ This would suggest that chalcopyrite did not deposit from an artesian solution. Wells found that hydrogen sulphide added to equal molecular weights of cupric and ferrous ions will not precipitate chalcopyrite.¹² Since this is the mechanism postulated in the artesian hypothesis, and since it does not work under laboratory conditions, doubt is cast on the artesian hypothesis.

Thus the evidence furnished by the presence of chalcopyrite,

¹¹ Wells, R. C.: The Fractional Precipitation of Some Ore-Forming Compounds at Moderate Temperatures. U. S. Geol. Surv., Bull. 609, pp. 18-20 and 23-24, 1915.

¹² *Idem.*

although not strong, favors the hydrothermal hypothesis over the artesian one.

The Inversion in the Order of Precipitation of Sphalerite and Galena.

According to the artesian hypothesis, lead and zinc ions are carried in solution in balance with bicarbonate ions. The metallic ions were precipitated when the release of pressure made hydrogen sulphide available. The figures quoted by Wells¹³ give the solubility product constant (K_{sp}) for galena as 1.5×10^{-12} and that for sphalerite as 43.0×10^{-12} . Hence:

$$\frac{K_{PbS}}{K_{ZnS}} = \frac{1.5 \times 10^{-12}}{43.0 \times 10^{-12}} = 1/30 \text{ (approximately).}$$

In other words, sphalerite will precipitate before galena only in a solution where the ratio of zinc to lead ions is more than 30:1. Moreover, while the two are coming down together, the ratio of the two sulphides in solution and in the resulting deposit will be thirty sphalerite to one galena. However, where sphalerite and galena are found to have precipitated together, the ratio is not more than 3 or 4 sphalerite to one galena. Since the ratio of 30:1 is not even approximated in the deposit during double precipitation, it follows that this mechanism for inverting the order of the beginning of precipitation cannot have been the one that controlled deposition.¹⁴

An excess of acid in the solution would reduce the concentration of the sulphide ion but this would have no effect on the order of the beginning of precipitation, nor would it cause the omission of any of the sulphides from the sequence.

Colloidal deposition might cause the inversion in the order of the beginning of precipitation. However, there is nothing in the display of perfectly intergrown crystals to suggest this, and there are no textures in the solid rock which suggest it; nor are such textures brought out by etching with aqua regia fumes.

¹³ *Op. cit.*

¹⁴ The ratio 30:1 is only an approximation but, since all the other solubilities given by Wells give an even larger ratio, it serves to illustrate the point involved.

It thus appears that the inversion in the order of the beginning of deposition of sphalerite and galena constitutes a serious objection to the artesian hypothesis.

In searching for an explanation of this inversion it is suggested that the ore-bearing solutions, according to the hydrothermal hypothesis, were given off at temperatures much higher than those that they finally reached through cooling. This range of temperature may furnish an explanation for the inversion in the order of the precipitation of sphalerite and galena.

It will be recalled that the paragenetic relations of the four sulphides—galena, sphalerite, chalcopyrite, and marcasite—were such that, although it is possible to say very certainly in what order they began to precipitate, it is impossible to say whether they stopped precipitating at the same or different times. All that can be said regarding the end of precipitation is this: after marcasite began to come down, a considerable amount of chalcopyrite (although less than the amount of marcasite), an intermediate amount of sphalerite, and very little galena precipitated. This can best be explained, in the writer's opinion, by assuming deposition of the four sulphides from a mixed solution by fractional precipitation and at different rates rather than by assuming the longer continuation of supply of some of the sulphides, all depositing at approximately the same rate.

It is possible, from the data furnished by Wells and from the observed behavior of the minerals, to construct a set of solubility curves which will roughly approximate the conditions which must have obtained during fractional precipitation from such a mixed solution. The solubilities at 18 degrees C. can be approximated from Weigel's values (given by Wells), but above this temperature there are no experimental data available for any of the sulphides. Thus, what happens to the curves at higher temperatures can only be interpreted from the relations of the minerals themselves and by assuming that the solubilities of the various sulphides in the mixed solution increase with a rise in temperature (Fig. 1). It must be emphasized that these curves are not based on experimental data but are constructed from the observed pro-

portions of the various sulphides in their various associations. The only two points that approximate known values are those just to the left of the second temperature division. The curves are not supposed to represent the curves these sulphides would show in simple solution, but are those which they show in a mixed solution of the composition of the ore-bearing solutions that deposited the Tri-State ores.

The following relations are of considerable service in determining the general form of the curves: (1) during the double precipitation of sphalerite and galena, the amount of sphalerite deposited exceeds that of galena; (2) during the triple precipitation of sphalerite, galena, and chalcopyrite, the amount of chalcopyrite deposited is greatest, that of sphalerite intermediate, and that of galena least; (3) during the quadruple precipitation of sphalerite, galena, chalcopyrite, and marcasite, the amount of marcasite is greatest, that of chalcopyrite next, that of sphalerite next, and that of galena least.

Relation (1) means that the curve of sphalerite solubility is steeper than that of galena; for over identical ranges of temperature less galena came down than sphalerite. Since this is true in the temperature ranges over which both came down together, it may be assumed that they continued to behave similarly up to the upper limit of temperatures attained.

Relation (2) means that the curve for chalcopyrite solubility is steeper than either that for galena or that for sphalerite; for over identical ranges of temperature less galena and sphalerite came down than chalcopyrite. In one exceptional case, the amount of chalcopyrite present in the specimen is many times greater than that of galena, although the amount of sphalerite present was much greater than that of chalcopyrite. In such a case the chalcopyrite might have reached its saturation temperature before galena and have been deposited first. The paragenetic studies show that this was the case, a large proportion of the chalcopyrite having come down before precipitation of galena began.

Relation (3) means that the curve for marcasite solubility is

steepest of all; for over identical ranges of temperature less galena, sphalerite, and chalcopyrite came down than marcasite.

It is on the basis of these deductions that the solubility curves given in Figure 1 were drawn. It must be remembered that the conditions in the mixed solutions were complicated by the facts that chalcopyrite is a double salt and that marcasite is a polysulphide. However, these two minerals give the sulphide ion on ionization and can therefore be considered components of a mixed solution in which the common anion was the sulphide.¹⁵

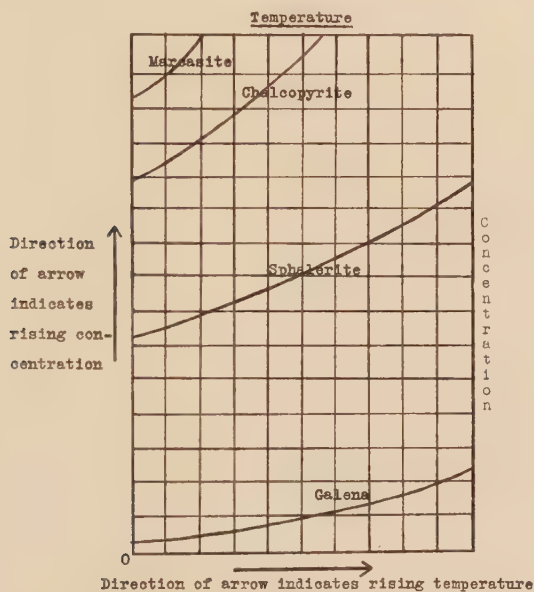


FIG. 1. Solubility curves deduced from the observed relations of the four sulphides. The curves apply only to a mixed solution of the composition of the ore-bearing solutions of the Tri-State area.

Reasons for Development of Well-Formed Crystals.—In the mixed solutions assumed, the concentrations would be very dilute and precipitation effected by gradual cooling would be a slow

¹⁵ For a discussion of precipitation from mixed solution and the principles involved, see:

Rastall, R. H.: *Physico-Chemical Geology*, pp. 54-57 and 181-183, 1927.

process. Therefore, the attractive forces of crystal growth would probably have segregated the sulphides into individual crystals. This segregation explains why it is possible to determine the order of the beginning of precipitation and to estimate the quantities of the various sulphides precipitated over the same period of time.

Additional Inferences Bearing on the Character and Temperatures of the Ore-Bearing Solutions.

The ore-bearing solutions must have carried the metallic ions in balance with either (1) the sulphide ion or (2) some other ion such as the bicarbonate, or the chloride. In case (1) precipitation would be due to cooling, in case (2) to reaction with hydrogen sulphide. Thus, for each molecule of sulphide precipitated, there would have been two hydrogen ions set free from combination with sulphide ion to form carbonic or hydrochloric acid with the remaining anion. In such a process, regardless of the strength of the acid formed, the resulting solution would give an acid reaction and fluid inclusions in the sulphides would indicate that reaction. The equation is as follows:



However, Newhouse found that the fluid inclusions in the Tri-State sulphides were neutral, as would be the case if the sulphides were introduced as such and precipitated by cooling.¹⁶ Hence, it seems most probable that the cause for precipitation of the sulphides was cooling alone.

From further work on the fluid inclusions Newhouse concluded that the deposition of sphalerite and galena took place at temperatures ranging from 135°–90° C.¹⁷ The curves given in Figure 1 are compatible with these data.

It may be concluded that the artesian hypothesis cannot ac-

¹⁶ Newhouse, W. H.: The Composition of Vein Solutions as Shown by Liquid Inclusions in Minerals. *ECON. GEOL.*, vol. 27, pp. 428–433, 1932.

¹⁷ Newhouse, W. H.: The Temperature of Formation of the Minerals of the Mississippi Valley Lead-Zinc Ores. *ECON. GEOL.*, vol. 28, p. 748, 1933.

count for the inversion in the order of the beginning of precipitation of sphalerite and galena, whereas the hydrothermal does.¹⁸

SUMMARY AND CONCLUSIONS.

The jasperoid is found to be composed of small xenomorphic crystals of quartz, the dark coloring being due to organic matter. The jasperoid is shown to be a replacement of the original dolomitic-limestone matrix rather than a filling of open spaces. Evidence is presented to show that the silica of the jasperoid was not deposited as a gel and that the vugs in the jasperoid were inherited from the dolomitic-limestone matrix rather than developed in the jasperoid itself.

The paragenesis of the minerals is discussed, evidence for the sequence is presented and the results summarized in a table. The most important results of the paragenetic studies are the discovery of (1) two periods of mineralization, separated by fracturing and (2) the inversion in the order of deposition of sphalerite and galena.

The observational evidence is discussed in its bearing on the leading hypotheses offered to account for the genesis of the ores. A hypothesis is offered to account for the inversion in the order of deposition. From this discussion it is concluded that the hydrothermal hypothesis can account for the observed phenomena while the artesian hypothesis cannot.

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CHICAGO, ILLINOIS,
Oct. 2, 1935.

¹⁸ The writer wishes to acknowledge his indebtedness to W. C. Pierce, Professor of Chemistry in the University of Chicago, for reading and discussing the section dealing with the inversion of the beginning of precipitation of sphalerite and galena, particularly the chemical theory involved.

